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REMARKS

Applicant's attorney wishes to express his appreciation to Examiner Rodney Lindsey for the constructive comments during the telephonic interview conducted June 27, 2004.

As suggested during the telephonic interview of June 27, 2004, claim 1 has been amended to recite a helmet shell composed of a polymeric material selected from the group consisting of poly-alpha-olefins, homopolymers of ethylene, copolymers of ethylene and other alpha-olefins, polyamides, polycarbonate, polyvinyl chloride, cellulose acetobutyrate, polybutylene terephthalate, polyoxymethylene polymers, polyester, and epoxy. The amendment to claim 1 has been made to emphasize the patentable distinctions of applicant's invention over the prior art. Such amendment incorporates into claim 1 the limitation of claim 2, which delineated a helmet shell composed of a polymeric material. Accordingly, claim 2 has been cancelled, without prejudice. Support for the amendment to claim 1 is found in the specification, e.g. at page 18, lines 15-20. Consequently, no new matter has been added.

It was also suggested during the June 27, 2004 telephonic interview that claim 9 be amended to recite an improved helmet system wherein the helmet shell is fabricated by injection molding a polymeric material into a molding cavity, the polymeric material being at least one material selected from the group consisting of poly-alpha-olefins, homopolymers of ethylene, copolymers of ethylene and other alpha-olefins, polyamides, polycarbonate, polyvinyl chloride, cellulose acetobutyrate, polybutylene terephthalate, polyoxymethylene polymers, polyester, and epoxy. Accordingly, claim 9 has been amended to emphasize the patentable distinctions of applicant's invention over the prior

art by incorporating the limitations of old claims 2 and 11. The amendment of claim 9 is clearly supported by page 18, lines 15-20 of the original specification.

In accordance with the discussion during the telephonic interview of June 27, 2004, claim 4 has been amended for the sake of clarity to recite a helmet system wherein the net or mesh comprises long-length para-aramid or high density polyethylene reinforcing fibers. Support for the amendment to claim 4 is provided by the specification; and in particular by the amended paragraph set forth at page 7 herein. Consequently, no new matter has been added.

New claims 11 to 12 have been added to provide adequate coverage for applicant's contribution to the art. Claim 11 depends from amended claim 1 and recites a helmet wherein the polymeric material is polycarbonate. Claim 12 depends from amended claim 1 and recites a helmet system wherein the full length of the fibers in the net or mesh is aligned in the direction of tension and compression imposed on the surfaces of the helmet during impact.

Support for newly presented claims 11 and 12 is found in the specification, e.g. at page 16, line 17; page 18, lines 13-14 and 16-20; page 21, line 13; and page 22, lines 10-12 and 17-21. Consequently, no new matter has been added.

As discussed in the telephonic interview of June 27, 2004, the Specification has been amended at page 16, line 16, to set forth a description of the known materials sold under the trademarks KEVLAR® and SPECTRA® and to provide antecedent basis for amended claim 4.

The Specification has been amended at page 22, line 22, to provide a description of one form of attachment means used to secure a helmet to a wearer's head, comprising a strap of known form, as depicted by Fig. 1A. The drawings have been amended to depict in Fig. 1A one form of attachment means, comprising a strap affixed to the helmet.

Support for the amendments to the specification and the drawings is found in the specification, e.g. at page 16, lines 5-7 and 16-24. Consequently, no new matter has been added.

The Examiner has required restriction under 35 USC 121 to one of the following inventions:

I. Claims 1-9, drawn to a helmet system, classified in class 2, subclass 411; and

II. Claim 10, drawn to a process for producing a helmet shell, classified in class 156, subclass 212.

During a telephone conversation with applicants' attorney Ernest D. Buff on April 5, 2004, a provisional election was made, with traverse, to prosecute the claims designated as Group I. Applicants hereby confirm the provisional election of the invention of Group I, claims 1-9, for further prosecution on the merits. In view of the special status accorded the instant case by virtue of applicant's Petition to Make Special under 37 CFR 1.102(d), which was granted on April 1, 2004, and to expedite prosecution, applicant hereby withdraws the provisional traverse of the foregoing restriction requirement.

Accordingly, claim 10, drawn to a process for producing a helmet shell, has been cancelled without prejudice to expedite prosecution of the instant application.

Objection has been raised to the drawings under 37 CFR 1.83(a) as not showing every feature of the invention specified by the claims. In particular, the Examiner has indicated that the attachment means of claims 1 and 8 are not shown on the drawings. Appended to this response is a sheet bearing amended Fig. 1A, including a strap denoted by reference numeral 20, which comprises one form of attachment means. As set forth herein, the specification has been amended correspondingly to describe the embodiment depicted by Fig. 1A, including strap 20. It is submitted

that amended Fig. 1A properly depicts the features of the invention delineated by claims 1 and 8, and thereby satisfies the requirements of 37 CFR 1.83(a).

Claim 4 has been rejected under 35 USC 112, second paragraph, as being of uncertain scope because of the presence of the trademark/tradenames KEVLAR and SPECTRA. Claim 4 has been amended to recite a net or mesh comprising long-length para-aramid or high density polyethylene reinforcing fibers and delete references to the trademark/tradenames KEVLAR and SPECTRA.

Applicant respectfully maintains that one of ordinary skill in the art would recognize KEVLAR as being a trademark under which is sold high strength para-aramid fiber and SPECTRA as being a trademark under which is sold high density, extended chain, high modulus polyethylene fiber.

KEVLAR is advertised by its maker, DuPont, as being a high strength para-aramid fiber. For the Examiner's convenience, a copy of a descriptive page available from DuPont through the World Wide Web at http://www.dupont.com/kevlar/whatiskevlar.html is provided herewith.

SPECTRA is advertised by its maker, Honeywell (formerly AlliedSignal), as being an extended chain, high modulus polyethylene fiber. For the Examiner's convenience, a copy of a descriptive page available from Honeywell through the World Wide Web at http://www.spectrafiber.com/fr_history.html is provided herewith. Also provided is a specification sheet for SPECTRA fiber 900 product, available from the Web at http://www.spectrafiber.com/products/spectra_900.html. Both documents describe SPECTRA fiber as being an extended chain, high modulus polyethylene.

Applicant further points to a technical paper by William C. Smith in which KEVLAR is described as a para-aramid and SPECTRA is described as a high density polyethylene. The paper and a related table are available on the World Wide Web at http://www.intexa.com/downloads/hightemp.pdf and http://www.intexa.com/hitemp.htm, respectively. The paper and table are submitted to evidence recognition of the meaning of the aforementioned trademarks by one skilled in the art. A copy of the Smith paper and chart are provided herewith for the Examiner's convenience.

Applicant respectfully maintains that the aforementioned documents are sufficient to establish that one of ordinary skill in the fiber art would have recognized the trademarks KEVLAR and SPECTRA as delineating materials known at the time of the filing of the present application and would have understood the subject matter recited by original claim 4. It is further submitted that the amendment of the present specification to characterize the terms KEVLAR and SPECTRA as referring to para-aramid and high density polyethylene is permissible under the provisions of MPEP 601.08(v), inasmuch as such identification would have been known and understood by a person of ordinary skill at the time of the filing of the present application. Consequently, it is respectfully submitted that no new matter has been added to the specification or to claim 4 by way of the present amendments.

As amended, claim 4 does not include any tradenames or trademarks. It is thus submitted that claim 4 is not of uncertain scope.

Accordingly, reconsideration of the rejection of claim 4 under 35 USC 112, second paragraph, as being of uncertain scope, is respectfully requested.

Claim 9 was rejected under 35 USC 103(a) as being unpatentable over US Patent 6,499,147 to Schiebl et al., which discloses protective headgear with a rigid shell.

The Examiner has pointed to the helmet system shown by Fig. 1 of Schiebl et al., comprising "polymeric foam core or shell 16 and the mesh or net 12, 14 of KEVLAR fiber". In the Examiner's view, the characterization of the KEVLAR as being of long-length fibers would have been obvious to one of ordinary skill in the art at the time of the invention. According to the Examiner, such characterization would have been relative, as any particular length fiber can be considered either short or long. The Examiner has further regarded claim 9 as being in product by process form.

Applicant respectfully traverses the Examiner's rejection of claim 9. It is respectfully submitted that Schiebl et al. fails to satisfy the criteria required to establish *prima facie* obviousness. In particular, applicant submits that: (i) Schiebl et al. fails to disclose or suggest every feature of the helmet recited by claim 9, as amended, and (ii) the Examiner has not provided any motivation that would lead one of ordinary skill in the art to modify the helmet disclosed by Schiebl et al. as required to provide the helmet delineated by amended claim 9. Significantly, Fig. 1 of Schiebl et al. depicts a helmet which has an inner layer 12 and an outer layer 14 permanently bonded to an <u>inner rigid foam core</u> 16 to form a rigid shell of relatively light weight." Col. 3, lines 25-27, emphasis added. Applicant respectfully disagrees with the Examiner's identification of element 16 depicted in Fig. 1 as being either a foam core or shell. Schiebl et al. specifically denotes element 16 as being an "inner rigid foam core" at col. 3, line 27. The shell to which the Examiner alludes is <u>either</u> a single layer (line 24) or the foam core <u>in combination</u> with inner and outer layers 12, 14 permanently bonded thereto (lines 26-27). Schiebl et al. further <u>teaches away</u> from any helmet

lacking an inner foam core. ["The core which is preferably made of polyethylene foam is important to the performance requirements. Although it may be possible to produce a shell of either a single composite layer, or multiple composite layers, without the light weight foam core spacing the inner and outer layers, the deflection properties of these shells would not match those of the laminated core shell when weight of the shell is considered." See col. 3, lines 43-50, emphasis added, of Schiebl et al.] Moreover, the Examiner has not provided any reference to substantiate the contention that one of ordinary skill in the art would understand KEVLAR fiber or woven fabric, such as that contemplated by Schiebl et al. (col. 3, lines 37-38), as having long fiber length. Applicant submits that the feature of a mesh or net of long fibers set forth in claim 9, when read in light of the instant specification, is not a mere relative description. In particular, applicant has delineated fibers of length greater than one inch as being long fibers. See, e.g. page 18, lines 22-23 and 25 of applicant's specification. On the other hand, applicant's helmet, as recited by amended claim 9, includes a three-layer structure in which the outer layers comprise a mesh or net of long length fibers integrally bonded with a polymeric material selected from the group consisting of poly-alpha-olefins, homopolymers of ethylene, copolymers of ethylene and other alpha-olefins, polyamides, polycarbonate, polyvinyl chloride, cellulose acetobutyrate, polybutylene terephthalate, polyoxymethylene polymers, polyester, and epoxy. Advantageously, such polymeric material withstands shear forces at the neutral axis of the helmet shell during impact loading (page 18, lines 20-22). Schiebl et al. provides no disclosure or suggestion that the foam core provides such capability.

That is to say, Schiebl et al. teaches use of an inner foam core to increase rigidity of the helmet shell. By this means Schiebl attempts to avoid damage, such as cracking, to the helmet

shell caused by high impact loading. In contrast to the Schiebl teaching, applicant has discovered that use of a three-layer structure in which the outer layers comprise a mesh of long length fibers integrally bonded with polymeric materials (e.g., materials of the type delineated by amended claim 9) on the inner and outer shell layers, imparts a unique combination of mechanical properties [e.g. high strength, toughness, crack resistance, and impact resistance] without need for an inner foam core. Advantageously, the helmet's strength is increased and its size and weight are decreased. Complex manufacturing processes required by Schiebl to integrate the core with the inner and outer shell layers are eliminated. The light weight, impact resistant helmet exhibits high strength, toughness and crack resistance, and is thereby especially well suited to withstand shear stress forces at the shell's neutral axis during impact loading, so that helmet service life and durability are substantially improved.

Accordingly, reconsideration of the rejection under 35 USC 103(a) of claim 9 over Schiebl et al. is respectfully requested.

Claims 1, 2, and 4-8 were rejected under 35 USC 103(a) as being unpatentable over Schiebl et al. in view of US Patent 6,434,755 to Halstead et al., which provides a helmet including a substantially rigid shell having a shell thickness defined by a substantially continuous exterior surface spaced apart from a substantially continuous interior surface. In view of the cancellation of claim 2, this rejection will be discussed with reference to remaining claims 1 and 4-8, as amended.

As set forth hereinabove in connection with the rejection of claim 9, applicant respectfully maintains that Schiebl et al. fails to disclose or suggest any helmet having the structure of applicant's helmet. In particular, Schiebl et al. do not teach a helmet having inner and outer surface layers reinforced with a fiber mesh or net, and bonded to a helmet shell composed of a

polymeric material selected from the group consisting of poly-alpha-olefins, homopolymers of ethylene, copolymers of ethylene and other alpha-olefins, polyamides, polycarbonate, polyvinyl chloride, cellulose acetobutyrate, polybutylene terephthalate, polyoxymethylene polymers, polyester, and epoxy, as required by applicant's amended claims 1 and 4-8.

Recognizing that Schiebl et al. fails to disclose or suggest any helmet including a pliable, padded inner helmet attached to the inner surface of the helmet shell, the Examiner has combined therewith the teaching of Halstead et al. It is respectfully submitted that Halstead et al. fails to remedy the deficiencies of Schiebl et al. with respect to the aforementioned helmet structure having a shell with inner and outer surfaces reinforced with a bonded net or mesh of long length fibers. Applicant thus submits that the combination of Schiebl et al. and Halstead et al. fails to disclose or suggest the helmet system delineated by amended claim 1. Amended claims 4-8 are submitted to be patentable over Schiebl et al. and Halstead et al. for at least the same reasons, inasmuch as they are dependent on amended claim 1 either directly or indirectly.

Accordingly, reconsideration of the rejection under 35 USC 103(a) of claims 1, 2, and 4-8 over the combination of Schiebl et al. and Halstead et al. is respectfully requested.

Claim 3 was rejected under 35 USC 103(a) as being unpatentable over Schiebl et al. in view of Halstead et al. as applied to claim 1 above, and further in view of World Patent WO 9400031 A1 to Ross.

Ross delineates a helmet having an outer shell formed as a sandwich comprising outer and inner composite layers each of resin and impact resistant material separated by an intermediate layer of resilient material.

The Examiner has pointed to Ross as teaching the formation of a composite laminate shell having a total thickness of about ¼ inch. Although the Examiner has not cited any specific reference within the Ross disclosure to substantiate his statement, he is believed to have in view page 3, second full paragraph, line 3, wherein it is stated that a layer of honeycomb material is inserted into a first shell, with NOMEX™ aramid material, "formed as a network of hexagonal cells, with a thickness of some 5-6 mm" (emphasis added) being disclosed as suitable. Applicant respectfully submits that any thickness of honeycomb material having a network of hexagonal cells is far from being relevant to the thickness suitable for applicant's helmet, which has an entirely different internal structure that lacks any such honeycomb material. The Examiner has not pointed to any evidence to establish that one of ordinary skill would regard the thickness of the Ross helmet structure as motivating the choice of a thickness of applicant's helmet. Nor is there any evidence given that one of ordinary skill would have a reasonable expectation of success when constructing a helmet having applicant's claimed structure, based on the teaching of thickness in Ross. The Examiner also has not pointed to any disclosure or suggestion in Ross that would remedy the lack of disclosure of applicant's structure as set forth hereinabove in connection with the rejection of claim 9 over Schiebl et al. or the rejection of claims 1-2 and 4-8 over Schiebl et al. in view of Halstead et al.

Accordingly, reconsideration of the rejection of claim 3 under 35 USC 103(a) as being obvious over the combination of Schiebl et al., Halstead et al. and Ross is respectfully requested.

US Patent 5,424,021 to Nakade et al; US Patent 2,423,076 to Daly; US Patent 5,075,904 to Shirasaki et al.; US Patent 2,766,453 to Frieder et al.; Japanese Patent JP 06173110 A

to Suzuki et al.; Japanese Patent JP 09041213 A to Nomura; US Patent Application US 2003/0139104 to Arai; US Patent 5,112,667 to Li et al; US Patent 3,353,187 to Lastnik et al.; US Patent 5,862,528 to Saijo et al.; and Japanese Patent JP 08311713 A to Nishimura et al. have been cited by the Examiner, but not applied. These patents obviously do not disclose or suggest the subject matter delineated by applicants' claims 1 and 3-9, as amended.

In view of the amendment to claims 1, 4, and 9; the cancellation of claims 2 and 10; the amendment to the drawings; the amendment to the specification; and the foregoing remarks, it is submitted that the present application, as delineated by claims 1 and 3-9, is in allowable condition. Reconsideration of the objection to the drawings, the rejection of claims 1-9, and allowance of this application as delineated by claims 1 and 3-9, along with newly presented claims 11-12, are, therefore, earnestly solicited.

Respectfully submitted,

Joseph Skiba

By

Ernest D. Buff
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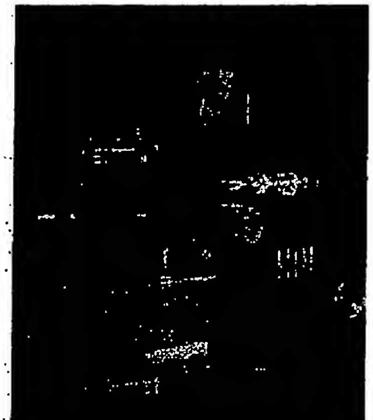
Spectra®

History of
Spectra® Fiber and Shield Technology


A technician at Honeywell's ballistic lab prepares to test material by loading bullets into the testing gun.

In the mid 1980s, AlliedSignal Inc. (now Honeywell) introduced Spectra® fiber. An entirely new type of synthetic yarn, it was one of the first commercially available extended chain, high-modulus polyethylene fiber. Because Spectra® fiber is a polyethylene—with a carbon-to-carbon molecular structure like that of a diamond—it creates a continuous filament yarn with incredible performance and endurance. Pound-for-pound ten times stronger than steel yet light enough to float, Spectra® fiber is one of the world's strongest and lightest manmade fibers. Spectra® fiber applications include **cut protection, ropes and cordage, vehicular and personal armor**, and **fishing line**, as well as various **specialty applications**.

The Spectra Shield® family of composite products began with the development of Shield technology by Honeywell in the late 1980s. Shield technology lays parallel strands of synthetic fiber side by side and holds them in place with a resin system, creating a unidirectional tape. Two layers are then cross-plied at right angles (0°/90°) and fused into a composite structure under heat and pressure. The pre-consolidated cross-plied material is then packaged as rolls, ready for shipping.

Shield technology was originally developed utilizing only Spectra® fiber, but over the years engineers have developed Shield products using other high-performance fibers such as aramid fiber in our Gold Flex® product.

In the last 15 years Shield technology and the Spectra Shield® family of composite products have revolutionized armor systems in ballistic resistant vests and hard armor applications used by law enforcement agencies and militaries throughout the world.

Spectra Technologies Mission

Spectra Technologies manufactures Spectra® fiber and develops performance-enriched, fiber-based technologies for applications where materials are mission-critical and when success frequently means expanding the accepted limits of performance. Spectra Technologies does this serving as a technical resource to its customers and the segments they serve.

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Honeywell

Spectra®

by

Spectra® fiber 900

HIGH-STRENGTH, LIGHT-WEIGHT POLYETHYLENE FIBER

Spectra® fiber 900 was the first commercially available extended-chain, high-strength polyethylene fiber and the first in a series of Spectra® fibers. Spectra® fiber has one of the highest strength-to-weight ratios of any man-made fiber. Its high tenacity makes it, pound for pound, 10 times stronger than steel, more durable than polyester and gives it a specific strength that is 40 percent greater than that of aramid fiber. Specific performance is dependent upon denier and filament counts.

Applications:

- Marine ropes
- Commercial fishing nets
- Industrial cordage & slings
- Law-enforcement & military helmets
- Cut-protection products

Product Characteristics:

- Light enough to float (0.97 specific gravity)
- High resistance to chemicals, water and ultraviolet light
- Excellent vibration damping
- Highly resistant to flex fatigue
- Low coefficient of friction
- Good resistance to abrasion
- Low dielectric constant makes it virtually transparent to radar

Physical Properties

(Nominal)		Spectra® fiber 900				
Weight/Unit Length	(Denier)	650[1]	650	1200	1600	4800
	(Decitex)	722	722	1333	1778	5333
Ultimate Tensile Strength	(g/den)	28	30.5	30	27	25.5
	(Gpa)	2.40	2.61	2.57	2.31	2.18
Breaking Strength	(lbs.)	40.1	44	79	95.2	270
Modulus	(g/den)	776	920	850	718	785
	(Gpa)	66	79	73	62	67
Elongation	(%)	4.1	3.6	3.9	4.4	3.9
Density	(g/cc)	0.97	0.97	0.97	0.97	0.97
	(lbs/in³)	0.035	0.035	0.035	0.035	0.035
Filament/tow		[illegible]	60	[illegible]	150	[illegible]
Filament	(dpf)	[illegible]	10.8	[illegible]	10.7	[illegible]

[1] Designed for knitted cut-resistant products

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HON-PF-PS9A

WHAT IS KEVLAR®?

Properties | History | Future | Applications

KEVLAR® is an advanced technology from DuPont that helps transform ordinary products into extraordinary ones. It combines high strength with light weight, and comfort with protection. Products made with KEVLAR®—from protective apparel and sports equipment to automotive parts and ropes used on the Mars Pathfinder—help those who use them to do more, to go farther, to be even better at what they do.

KEVLAR® is 5 times stronger than steel on an equal weight basis, yet, at the same time, is lightweight, flexible and comfortable. It is this unique combination of attributes that enable those who use it to realize success, to perform to their fullest potential and to achieve their personal best.

This is your glimpse into the world of KEVLAR® . Read on to learn how and why this brand has become an integral part in improving performance in every day life and the many ways KEVLAR® can make an impact in yours.

A History of the Power of Performance
The year is 1965. Two research scientists working in a corporate lab create a remarkable fiber. The technology they developed was one that enhanced strength, light weight and flexibility.

It offered numerous other benefits—ones that could be offered in a variety of forms. The scientists were Stephanie Kwolek and Herbert Blades. The company was DuPont. And the technology was KEVLAR® .

And, because of the superior protection it provides, KEVLAR® brand fiber quickly became the technology of choice for bullet-resistant vests. In fact, police officers have relied on the KEVLAR® brand for more than 25 years because of the superior bullet-stopping power it offers. That power and protection comes packed at an extremely light weight, which provides both comfort and freedom of movement to those that wear KEVLAR®.

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The Properties of KEVLAR®
KEVLAR® is one of the most important manmade organic fibers ever developed. Because of its unique combination of properties, KEVLAR® is used today in a wide variety of industrial applications. KEVLAR® para-aramid fiber possesses a remarkable combination of properties that has led to its adoption in a variety of end-uses since its commercial introduction in the early 1970's.

Fibers of KEVLAR® consist of long molecular chains produced from poly-paraphenylene terephthalamide. The chains are highly oriented with strong interchain bonding which result in a unique combination of properties.

General Features of KEVLAR® :

- High Tensile Strength at Low Weight
- Low Elongation to Break High Modulus (Structural Rigidity)
- Low Electrical Conductivity
- High Chemical Resistance
- Low Thermal Shrinkage
- High Toughness (Work-To-Break)
- Excellent Dimensional Stability
- High Cut Resistance
- Flame Resistant, Self-Extinguishing

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The Many Applications of KEVLAR® ?

Today, the story of KEVLAR® extends far beyond that DuPont laboratory. In the almost 40 years since its discovery, KEVLAR® has played a significant role in many critical and diverse applications:

- Ropes that secure the airbags in the crucial landing apparatus of the Mars Pathfinder
- Small-diameter, lightweight ropes that hold 22,000 pounds and help moor the largest U.S. Navy vessels
- Shrapnel-resistant shielding in jet aircraft engines that will protect passengers in case an explosion occurs
- Run-flat tires that allow for greater safety because they won't ruin the rim when driving to the nearest assistance
- Gloves that protect hands and fingers against cuts, slashes and other injuries that often occur in glass and sheet metal factories
- Kayaks that provide better impact resistance with no extra weight
- Strong, lightweight skis, helmets and racquets that help lessen fatigue and boost exhilaration

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The Future of KEVLAR®
KEVLAR® is a highly creative material...a constantly improving, evolving technology. Jobs, activities or products that stand to benefit from integrating the dynamic technology of KEVLAR® are limited only by your imagination.

We invite you to check this site often to see the enhancements and updates we will be making for the use of KEVLAR® in applications as diverse as personal body armor, personal life safety equipment including hunting apparel, and personal performance apparel including athletic shoes, hiking boots and parkas.

As you can see, the application possibilities for KEVLAR® are endless.

KEVLAR®. It's the power of performance.

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High Performance And High Temperature Resistant Fibers
- Emphasis on Protective Clothing

I. INTRODUCTION

Faster, stronger, lighter, safer ... these demands are constantly being pushed upon today's researchers and manufacturers, including protective clothing - routine or specialized. High performance and high temperature resistant fibers aid enormously in allowing products to meet these challenges. The markets and products which are facilitated by the use of these fibers go far beyond the scope and awareness of most people. This paper intends to provide a solid overview of the definitions, properties, products and end uses associated with some of the most common high performance and high temperature resistant fibers used today. *It is stressed that not all high performance materials are presented.*

Before exploring details these materials, it is important to define the parameters of high performance and high temperature resistant fibers. For this discussion, the latter is classified as ***a synthetic fiber with a continuous operating temperature ranging from 375⁰ F to 600⁰ F***.

The classification of high performance is less rigid and can be broken down into various segments. Generally speaking, fibers are said to be either ***commodity*** or ***high performance.*** Commodity fibers are typically used in a highly competitive price environment which translates into large scale high volume programs in order to compensate for the (often) low margins.

Conversely, high performance fibers are driven by ***special technical functions that require specific physical properties unique to these fibers***. Some of the most prominent of these properties are: tensile strength, operating temperature, limiting oxygen index and chemical resistance. Each fiber has a unique combination of the above properties which allows it to fill a niche in the high performance fiber spectrum.

For comparative purposes carbon, glass and high density polyethylene are also referenced. Although these fibers don't necessarily meet all of the requirements of the stated definitions, they commonly compete in the high performance market and should therefore be referenced.

The following presents some basic characteristics of each classification:

Commodity Fibers	High Performance Fibers
Volume Driven Price oriented Large scale, line-type production	Technically Driven Specialty oriented Smaller batch-type production

www.intexa.com/downloads/hightemp.pdf

PAGE 25/45 * RCVD AT 6/28/2004 5:32:31 PM [Eastern Daylight Time] * SVR:USPTO-EFXRF-1/2 * DNIS:8729306 * CSID:908 901 0109 * DURATION (mm-ss):16-20

II. BASIC PROPERTIES

Tensile strength is often the determining factor in choosing a fiber for a specific need (see chart 1). A major advantage of high strength fibers over steel, for example, is the superior strength-to-weight ratio that such fibers can offer. Para-aramid fiber offers 6-8 times higher tensile strength and over twice the modulus of steel, at only one-fifth the weight, but in applications where strength is not of paramount importance, other properties must be evaluated.

Temperature resistance often plays an integral role in the selection of a fiber. Heat degrades fibers at different rates depending on the fiber type, atmospheric conditions and time of exposure. The key property for high temperature resistant fibers is their continuous operating temperature. Fibers can survive exposure to temperatures above their continuous operating temperatures, but the high heat will begin to degrade the fiber. This degradation has the effect of reducing the tensile properties of the fiber and ultimately destroying its integrity.

A common mistake is to confuse *temperature resistance* with *flame retardant ability*. Flame retardant ability is generally measured by the Limiting Oxygen Index. LOI, basically, is the amount of oxygen needed in the atmosphere to support combustion. Fibers with a Limiting Oxygen Index (LOI) greater than 25 are said to be flame retardant, that is there must be at least 25% oxygen present in order for them to burn. The LOI of a fiber can be influenced by adding a flame retardant finish to the fiber. FR chemicals are either added to the polymer solution before extruding the fiber or added to the fiber during the spinning (extrusion) process. In addition, impregnating or topically treating the fiber or the fabric, flame retardant properties are often added directly to fabrics (such as FR treating cotton fabrics).

Just as heat can degrade a fiber, chemical exposure, such as contact with acids or alkalis, can have a similar effect. Some fibers, such as PTFE (i.e. DuPont's Teflon), are extremely resistant to chemicals. Others lose strength and integrity quite rapidly depending on the type of chemical and the degree of concentration of the chemical or compound.

III. FIBER FORMS AND PRODUCT FORMS

Fibers are available in several different forms. The most common forms used are:

- Staple Fiber – filaments cut into specific lengths – usually spun into yarn
- Chopped Fiber – coarser, cut to specific, often short, lengths to add to mixture
- Monofilament – a single (large) continuous filament yarn – like fishing line
- Multifilament – extruded continuously with many filaments in the bundle.

These basic forms of fiber are then further processed into one of four major converted forms. These converted forms can be categorized into four groups:

- Spun yarn
- Knitted fabri

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Woven fabric

Nonwoven fabric

Most are familiar with yarn, woven and knitted fabrics. Nonwoven fabrics may be another story. The most common types of nonwoven fabrics are – based on bonding and manufacturing processes - are:

- Needlefelts – the fibers are mechanically entangled with barbed needles
- Dry-laid – chemical or thermal bond – many different forms, including
- Direct formed - spunbond and melt-blown (may be further bonded or combined)
- Stitch Bond – sewn bond
- Wet-laid – paper making process
- Hydro-entangled (spunlace) – water jet entangled – mechanical bond

Many of the fibers are used in very similar end uses, but based on differences of specific properties, *each fiber tends to find its own niche where it has an advantage over the others.*

IV. FIBER PROPERTIES AND THEIR APPLICATIONS

A. Meta-aramid: Nomex® (DuPont), TeijinConex®, TeijinConex HT® (Teijin)

Perhaps the best known and most widely used of the aramid fibers (Nomex is familiar to many), meta-aramids are best known for their combination of heat resistance and strength. In addition, meta-aramid fibers do not ignite, melt or drip; a major reason for their success in the FR apparel market. In comparison to commodity fibers, meta-aramids offer better long-term retention of mechanical properties at elevated temperatures. Meta-aramids have a relatively soft hand and tend to process very similarly to conventional fibers, giving them a wide range of converted products. Meta-aramids are available in a variety of forms, anti-stat, conductive, in blends (with other high performance fibers), etc.

TeijinConex HT high tenacity type meta-aramid has significantly higher tensile strength of other meta-aramids. This high strength allows it to bridge the gap between meta-aramid and para-aramid fiber when strength is the primary concern.

M-aramid Properties	Value
Tenacity g/de	3.8-7.2
Elongation (%)	25-40
Limiting Oxygen Index	30
Chemical resistance	Mild-Good

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Operating temperature	400^0 F

Typical Applications for Meta-aramid Fabrics (not an exhaustive list)

M-Aramid Fabric Form	Application
Needlefelt	Automotive Business machine parts Cushion material Hot gas filtration **Safety & Protective clothing** Thermal insulation Thermal spacers
Woven fabric	Hot gas filtration Loudspeaker components Reinforcement: composites and rubber **Safety & Protective clothing** Thermal insulation
Wet-laid nonwoven	Business machine parts Battery separators Heat shields
Dry laid nonwoven	Business machine parts Electrical insulation Heat shields Hot gas filtration Laminate support base Thermal spacers
Spunlace nonwoven	High temperature filtration **Safety & Protective clothing** Laminate support base

B. Para-aramid: Kevlar® (DuPont), Twaron® (Acordis), Technora® (Teijin)

Due to their highly oriented rigid molecular structure, para-aramid fibers have high tenacity, high tensile modulus and high heat resistance. Para-aramid fibers have similar operating temperatures to meta-aramid fibers, but have 3 to 7 times higher strength and modulus, making them ideal for reinforcement and protective type applications.

There are two types of para-oriented aramid fibers:

- Homo-polymer - Kevlar and Twaron
- Co-polymer - Technora

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Although para-aramids are high in strength, there is some problem with chemical resistance. Homopolymer para-aramids have relatively weak resistance to strong acids and bases. Kevlar and Twaron, for instance, cannot be bleached with chlorine and are often not approved for food handling in protective gloves. The fine surface structure of Technora copolymer allows it to have much higher chemical resistance. Kevlar has new forms with increased strength and improved properties.

Co-polymer para-aramids have advantages with increased abrasion resistance and steam resistance – useful properties in many protective applications.

Typical properties of para-aramids are as follows:

Properties	Value
Tenacity g/de	22 - 26
Modulus g/de	460-1100
Elongation	2.4 – 4.4
Continous operating temperature (^{0} F)	375
Limiting Oxygen Index (LOI)	25 - 28
Chemical resistance	Mild - Good

Para-aramids are often blended with other fibers to impart some of their high strength properties to the blend or mix. A 60/40 blend of Kevlar and PBI, is the most widely used material for firemen's premium turn out coats. The Kevlar helps overcome some of the "textile" deficiencies (processing, strength) in the PBI; the PBI's softness, moisture regain, and high temperature properties improves the performance characteristics of the Kevlar. And it reduces the cost of the otherwise expensive PBI fiber – over $70/lb.

Such synergy is often utilized in high performance fiber blends – one fiber contributing unique properties or improving characteristics of specialized materials – such as improved processing of otherwise difficult-to-handle fibers, or to reduce overall cost.

The following table shows typical applications, in fabric form, for para-aramids. The list is not exhaustive.

Form	Application

The ITA Hi-Performance Fibers Chart

There are many high performance fibers on the market. The following chart, and the accompanying Table 2 with brand names, should help to give you some idea of their properties and assist in choosing their use. It is not all inclusive, but does include the most commonly available materials. To select the right fiber, many factors should be considered, not just properties -- but it is a good place to start. And since things are changing, so will the availability of some of the fibers. Please contact ITA should you have questions or need assistance.

FIBERS & PROPERTIES	Aramid[3] M = meta P = para	PAN/ Carbon	HDPE (4)	Glass	Melamine	PBI	PBO	Novaloid Phenolic	Polyacrylate	Polyarylate liquid crystal	PPS
FIBER PROPERTIES											
Tenacity - dry g/d	4.0-5.3 M 21-27 P	24	24-35	15.3	1.8	2.6-3.0	42	1.3-2.4	1.3-1.7	26-29	3.5
Tensile - 000 psi	90 M 400 P	31	375-435	500	30	50	N/A	20-30	25-33	525-585	61
Elongation at break %	22-32 M 2.5-4.0 P	19	2.8-4.4	4.8	12	25-30	2.5-3.5	30-60	20-30	3.3	40
Moisture Regain %	6.5 M 4.0 P	9	0	< 0.10	5	15	0.6-2.0	6-7.3	12	<0.10	0.6
Specific Gravity	1.38 M 1.44 P	1.4	.97	2.5	1.44	1.43	1.50	1.27	1.5	1.41	1.37
Avg. Toughness - g/d	0.30 M 0.85 P	N/A	N/A	0.37	N/A	0.4	N/A	N/A	N/A	N/A	N/A
Abrasion Resistance	Good M Poor P	Poor	Good	Poor	Fair	Good	Excel	Poor	Fair	Excel	Good
Resilience	Excellent	Poor	Fair	Poor	Fair	Excel	Excel	Fair	Good	Good	Good
CHEMICAL RESISTANCE											
Solvents	Excel M Good P	Good	Excel	Excel	Excel	Excel	Excel	Excel	Good	Excel	Excel
Acids: dilute: concentrated:	Good M Fair P	Good Poor	Excel Excel	Excel Excel	Good Poor	Excel Excel	Good Fair	Excel Poor[1]	Excel Excel	Excel Excel	Excel Good
Alkalies: dilute:	Good M	Good	Excel	Fair	Excel	Excel	Excel	Excel	Excel	Excel	Excel

concentrated:	Good P	Good	Excel	Fair	Excel	Good	N/A	Excel	Excel	Excel	Excel
Ultraviolet (UV)	Poor	Good	Excel	Excel	Good	Good	P-Good	Excel	Excel	Poor	Excel
THERMAL PROPERTIES											
Limiting Oxygen Index (LOI)	30 M 29 P	55	N/A	> 100	32	42	68	33	43	37	34
Thermal Conductivity (BTU - in/hr^2 per ^{0} F)	0.26 M 0.30 P	< .03	N/A	7.2	0.20	0.26	<0.3	0.28	0.31	3.81(5)	0.3
Usable Temp. ^{0} C Short term: Continuous:	 315-370 230	 V-High 220	 Melts at 147(4)	 V-High 315	 260-370 >200	 > 595 315	Decomp 660 >300	Decomp 400 205	 (2) 160	Decomp >400 >200	 260 205
Smoke Emission - Density:	1.0	N/A	N/A	Low	Low	Trace	Low	< 0.30	Trace	Low	N/A
RELATIVE COST											
1 = Low 4 = High	3	3	2	2	2	4	4	2	3	3	3

NOTES: 1 - Nitric and Sulfuric SOURCE: Producers literature

2 - Auto ignition @ 450^0 C & 100% O_2 and ITA database

3 - M - Meta-aramid (as Nomex); P - Para-aramid (as Kevlar)

4 - HDPE is not FR/High Temp, but low melt fiber with very high strength for high performance applications

5 - Polyarylate liquid crystal data is for Vectran Type HS. Conc acids <90%, Bases <30%; Thermal conductivity reported as (10)-4 cal/s/cm'C @ 23 de

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Table 1 - Properties of Selected High Performance Fibers

ARAMID **Meta-Aramid:** **Nomex (DuPont)** **Conex (Teijin)**	**PBI - POLYBENZIMIDAZOLE** **PBI (Celanese)**	**PTFE - Fluoroca** **Teflon (DuPont** **Toyoflon (Toyc**
Para-Aramid:	**POLYARYLATE**	**PBO -**

Kevlar (DuPont) **Technora** (Teijin) **Twaron** (Teijin)	(Liquid Crystal) **Vectran** - (Celanese)	POLYPHENYLENEBENZ **Zylon** (Toyobo)
GLASS: (Various producers) **E-Glass** **S-Glass** **Cardable Glass** **Miraflex** - Owens Corning	**POLYAMIDE IMIDE** (Sometimes classified as meta-aramid) **Kermel** (Rodia) **POLYIMIDE** **P84** (Inspec Fibers)	**PAN/CARBON** - (Preoxidized polyacrylonitril - partial listing **Curlon** (ORCO **Fortafil** (Akzo **Hexcel CF** (He: **Lastan** (Asahi (**Panotex** (Lanto Carbon) **Tenax** (Tenax - Akzo/Toho) **Torayca** (Toray **Thornel** (Amoc
HDPE (High Density Polyethylene): **Spectra** - (Honeywell Performance Fibers)	**PPS/SULFAR** - POLYPHENYLENE-SULFIDE **Ryton** (Toyobo) **Procon** (Toyobo) **Toray PPS** (Toray)	**SILICA** **Leached Glass** **Quartzel:** (Saint-Gobain (

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Dyneema (Toyobo/Dyneema, DMS)		
MELAMINE **Basofil** (Basofil Fibers LLC)	**PEEK -** POLYETHERETHERKETONE **PEEK** (Toyobo))	**CERAMIC** **Nextel** (3M)

Table 2 - Generic/Trade Names/Producers - *Selected* High Performance Fibers

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Needlefelt	Cushion material **Safety and protective clothing** Thermal insulation Thermal barriers
Woven fabric	Reinforcement: composites and rubber Sporting goods Thermal insulation Mechanical rubber goods **Safety and protective clothing** Ballistic application
Wet-laid nonwoven	Friction materials Heat shields
Yarn	Reinforcement: composites and rubber Sewing thread Ropes and cables **Safety and protective clothing** (sewing thread)

C. Fluorocarbon fibers (PTFE) : Teflon® (duPont), Toyoflon® (Toray)

PTFE (polytetrafluoroethylene) fibers offer a unique blend of chemical and temperature resistance, coupled with a low friction coefficient. PTFE is virtually chemically inert, and is able to withstand exposure to extremely harsh environments. The coefficient of friction for PTFE, the lowest of all fibers, makes the fiber suitable for a wide range of applications such as bearing replacement material and release material when stickiness is a concern. The fiber's low friction coefficient, as well as their low tensile strength, makes PTFE fibers difficult to process, and difficult to blend with other fibers. PTFE sewing thread is ideal for a number of PC and harsh applications. *The material is also made into breathable, porous membranes laminated to fabrics for protective uses.*

The following properties area typical of PTFE materials

PTFE Properties	Value
Tenacity g/de	2
Elongation (%)	25
Limiting Oxygen Index (LOI)	95
Chemical resistance	Excellent
Friction coefficient	0.2
Operating temperature (^{0}F)	500

The following table lists typical applications for PTFE yarns/fibers.

PTFE Form	Application
Needlefelt	Automotive Bearing replacement Hot gas filtration Release fabrics
Woven fabric	Conveyor belts Mechanical rubber goods Gasket tape
Wet-laid nonwoven	Battery separators Heat shields Liquid filtration
Monofilament	Release fabrics Filtration fabrics
Yarns	Mechanical rubber good Sewing thread
Membranes	Filtration Safety and Protective (vapor barriers, breathable membranes)

D. PPS: Ryton® (Amoco/Successor), Procon® (Toyobo), Toray PPS® (Toray)

Polyphenylene sulfide fibers combine moderate temperature resistance with excellent chemical resistance. PPS fibers also have very good flame resistance thanks to their high LOI. The low moisture regain of PPS often takes away from its use in protective apparel; the fiber has an uncomfortable hand, but the good chemical resistance makes it very attractive for industrial applications, especially for filtration.

PPS Properties	Value
Tenacity g/de	3.5 – 4.5
Elongation (%)	32 - 49
Limiting Oxygen Index (LOI)	34
Chemical resistance	Very Good

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Operating temperature (^{0}F)	500

The following represent typical applications for PPS. The list is rather short, but the applications are important.

Form	Application
Needlefelt	Hot gas filtration
Woven fabric	Liquid filtration Laundry materials Rubber industries

E. Melamine: Basofil® (BASF)

Basofil has recently entered the high temperature fiber market, one of the newest fibers to do so, and has made a rapid impact. Compared to fibers with comparable properties, its low cost is an advantage and should result in its being evaluated in a number of areas. Based on melamine chemistry, Basofil offers a high operating temperature and a high LOI and typically targets hot gas filtration and safety and protective apparel markets. Because of its variable denier and staple length, low tensile strength, and difficulty in processing, Basofil is generally blended with stronger fibers such as aramids. It is more often used in needled products or yarns made from wrapped spinning techniques, though recent advances have led to satisfactory ring spun yarns, blended with other fibers, such as para-aramids, suitable for weaving into firemen's turnout gear. This development may lead the way to its adoption in other areas.

Basofil Properties	Value
Tenacity g/de	2.0
Elongation (%)	18
Limiting Oxygen Index (LOI)	32
Chemical resistance	Mild - Good
Operating temperature (^{0}F)	400

Having only recently been introduced, Basofil has a limited range, but rapidly growing, of on-going applications. Potential looks promising for this high performance, low cost fiber to find its way into a number of existing areas, especially as processing difficulties are overcome.

Form	Application

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Needlefelt	Hot Gas Filtration Safety and Protective Applications Thermal Insulation
Woven Fabric	Safety and Protective Applications

F. PBO: Zylon® (Toyobo)

Poly-phenylene benzobisoxazole is another new entrant to the high performance organic fibers market. The only entrant thus far, Toyobo's Zylon has outstanding thermal properties and has almost twice the tensile strength of conventional para-aramid fibers . Its high modulus makes it an excellent candidate for composites reinforcement. Due to its high LOI, PBO has over twice the flame retardant properties of meta-aramid fibers. PBO is still in its pilot plant stages, with commercial production just coming on stream.

PBO Properties	Value
Tenacity g/de	42
Modulus g/de	1300
Elongation (%)	3.5
Continuous operation temp. (°F)	550-600
Limiting Oxygen Index (%)	68
Chemical resistance	Mild-Good

The following lists some of the possible areas of application for PBO materials.

Form	Application
Woven Fabric	Reinforcement composites and rubber Sporting goods Thermal shields **Safety and protective clothing** Ballistic applications Mechanical rubber goods
Needlefelt	Aluminum spacers Heat shields

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Yarn	Reinforcement composites and rubber Sewing thread Ropes and cables

G. PBI: **PBI (Celanese)**

Polybenzimidazole is an organic fiber with excellent thermal resistant properties and a good hand. PBI does not burn in air and does not melt or drip. The high LOI coupled with its good chemical resistance and good moisture regain make PBI an excellent fiber for fire blocking end uses such as safety and protective clothing and flame retardant fabrics. Its physical properties are relatively low, but PBI is processed on most types of textile equipment. It blends well with other materials such as carbon and aramid fibers and is most often done for performance reasons as well as cost. PBI has had significant success in the fireman's apparel market where, blended in a 60/40 para-aramid/PBI mixture, it has become the standard "premium" material. PBI's characteristic gold color blends well with other materials for a pleasing appearance. Its main drawback is its very high price – over $70 per pound.

PBI Properties	Value
Tenacity g/de	2.7
Modulus g/de	32
Elongation (%)	29
Continuous operation temp. (^{O}F)	482
Limiting Oxygen Index (%)	41
Chemical resistance	Good - Excellent

Typical applications for PBI include the following:

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Form	Application
Needlefelt	Thermal insulation **Safety and protective clothing** Fire blocking
Woven Fabric	Thermal insulation **Safety and protective clothing**

H. Polyimide (PI): P-84® (Inspec)

P-84 is a polyimide fiber developed by Lenzing AG (Austria) and now produced and marketed by a spin-off company, Inspec Fibres GmbH in Austria. P-84 provides a high operating temperature with very good flame retardant properties and good chemical resistance. P-84 fiber touts a unique multi-lobal irregular cross section. This irregular structure offers greater surface area than a conventional round cross section, and has achieved widespread recognition for P-84 fiber in the hot gas filtration market. Due to its high price however, actual use of P-84 in the filtration market is limited to areas where extreme emission controls are necessary. It has also made inroads in the protective clothing market, especially in Europe.

P-84 Properties	Value
Tenacity g/de	4.2
Elongation (%)	30
Continuous operation temp. (^{O}F)	500
Limiting Oxygen Index (%)	38
Chemical resistance	Good

Typical applications for P-84 polyimide fabrics include the following:

Form	Application

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Needlefelt	Thermal insulation **Safety and protective clothing**
Woven Fabric	Thermal insulation **Safety and protective clothing**

I. Carbon Precursor: Lastan® (Asahi)

Lastan is a flame-retardant fiber made by pyrolytic carbonization of a modified acrylic fiber. Carbon precursor fibers are partially carbonized fibers which transform into carbon or graphite fiber when they undergo further carbonization in an inert atmosphere at high temperature. Carbon precursor fiber combines a high operating temperature with excellent flame resistance. Since this fiber is relatively weak and has limited abrasion resistance, it is often blended 50%/50% with para-aramid fibers creating a strong durable product still having an LOI of 45. Due to its soft hand, Lastan fiber is desirable in apparel applications as well as certain industrial applications.

Lastan® Properties	Value
Tenacity g/de	2
Elongation (%)	15
Continuous operation temp. (^{O}F)	392
Limiting Oxygen Index (%)	60
Chemical resistance	Mild
Electrical resistance	$10^8 - 10^{10}\ \Omega$ cm

Typical applications for carbon precursor fabrics include the following:

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Form	Application
Woven Fabric	Welding blankets Aluminized fabrics Thermal barriers **Safety and protective clothing**
Needlefelt	Welding blankets Thermal barriers **Safety and protective clothing**
Dry Laid Nonwovens	Aluminized fabrics - S&P

J. Carbon fiber: PAN (polyacrylonitrile) and Pitch based

There are different categories of carbon fibers based on modulus, tensile strength, and final heat treatment temperature. In the carbonization process, temperature exposures range from 1000^0 C to 2000^0 C, each different level of exposure creating a different property for the fiber. For example, high-modulus type is processed at 2000^0 C, 1500^0 C for high strength type, and 1000^0 C for low modulus and low strength type. The main carbon fibers are made from polyacrylonitrile (PAN) based and pitch based, and are well known for their composite reinforcement and heat resistant end uses.

Carbon Fiber Properties	PAN	PITCH
Tenacity g/de	18-70	14-30
Modulus g/de	1640 - 3850	1000 5850
Elongation (%)	0.4-2.4	0.2 – 1.3
Continuous operation temp. (^{O}F)	570 - 1000	570 - 1000

Carbon fibers find application in many forms and many areas. Some include the following:

Form	Application

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Woven Fabric	✍ Aircraft and aerospace ✍ Automotive ✍ Sports & recreational equipment ✍ Marine ✍ General engineering
Yarn/Fiber	✍ Reinforcement composites and rubber ✍ Filtration

K. Glass:

Glass is an inorganic fiber, which is neither oriented nor crystalline. Glass fibers were one of the first "man-made" fibers, commercialized in the late 30's. Widely used as insulation (glass batts in home insulation and industrial insulation in mats and fabric form). It is widely used in reinforcing thermoplastic composites in products from circuit boards to boat hulls. High temperature filtration is another high volume use. The ingredients normally used in making glass fibers are: silicon dioxide, calcium oxide, aluminum oxide, baron oxide, plus a few other metal oxides.

<u>Glass types:</u>

A - alkali-containing glass composition.
AR - alkali-resistant for reinforcing cement.
C - chemically-resistant glass composition.
E - standard uses, this composition has high electrical resistance.
HS magnesium-alumina-silica glass. High strength.
S - composition similar to HS glass.

The following chart is representative of the properties of various glass fibers.

Properties	E-glass	AR-glass	S-glass
Tensile Strength (g/de)	35	46	35
Modulus (g/de)	524	1250	620

Elongation (%)	4.8	2	5.4
Refractive index	1.547	1.561	–
Density (g/cm3)	2.57	2.68	2.46
Coefficient of thermal expansion (10^7 ^{0}C)	50-52	75	23-27
Dielectric(10^{10}Hz) Constant	6.1-6.3	--	--

Typical glass applications include:

Form	Application
Woven Fabric	Automotive Filtration Reinforcement - plastic/rubber/cement Thermal insulation Printed circuit boards - electrical
Needlefelts	Aircraft and aerospace Cushion material Filtration Thermal insulation and spacers Acoustic insulation

L. High Density Polyethylene - HDPE: Spectra® (Honeywell), Dyneema® (Dyneema)

HDPE fibers offer strength similar to that of para-aramids. Developed in Japan by Dyneema, and known throughout the world as Dyneema, except in the US where the process is licensed to AlliedSignal and is known as Spectra. Light in weight, the fiber has a specific gravity of less than 1, tough yet lighweight products can be made, including rope and cordage that floats as well as soft and semi-rigid body armor and in cut resistant materials such as gloves that are

lighter than competitors, reducing fatigue in use. In addition to high tenacity, HDPE fibers have very good abrasion resistance and excellent chemical and electrical resistance. HDPE fibers are inherently "slick" and difficult to adhere to, a drawback in some areas but not of concern in others. They can be bleached and sterilized and used for food handling gloves, among others. The HDPE fibers have low melting points, however, so their continuous operation temperature is a relatively low 250^0 F. There are a number of volume areas where temperature is not crucial..

HDPE Fiber Properties	Value
Tenacity g/de	30
Elongation (%)	3.
Continuous operation temp. (^{O}F)	250
Modulus g/de	1400
Chemical resistance	excellent

Typical applications and forms of HDPE fibers include:

Form	Application
Yarns	Marine ropes and cordage Sail cloth
Woven Fabric	Marine **Safety and protective products** Reinforcement of composites (sport, pressure vessels, boat hulls, implants) Medical

V. CONCLUSION

High performance fibers and high temperature resistant fibers offer numerous advantages over traditional materials. Higher strength, lighter weight, higher operating temperatures and flame-retardant ability are some of the most prominent features of these fibers. These

outstanding properties create opportunities to manufacture products that historically could not be made due to technical constraints. The protective clothing area is one of those markets.

Each of these fibers discussed have their limitations. It is not as easy to take these materials "off the shelf" except for a few well-distributed ones. Surely, some are more readily available than others -- the aramids, HDPE, for instance -- but most are less so and should be considered as engineering or specialized materials to be used where their properties are paramount. Review thoroughly each fiber for the properties it brings to the product.

High performance fibers allow companies to enter niche markets, which typically provide higher profits as well as strong barriers to entry for the competition. Even in the high performance area, many markets have become "commodity" applications, particularly the aramids in protective clothing. The protective clothing market will continue to bring new opportunities for high performance fibers as the fiber manufacturers expand their current product lines as well as create new and exciting specialized materials.

<u>Special notation:</u> ***The original authors of most of this text, from Aramid Ltd, graciously allowed me to edit and revise some of their text and data in order to develop this version for PCC'99. Inquiries concerning the data, and many of the fibers in question, can be forwarded to them or to me. There is no connection between Aramid Ltd and Industrial Textile Associates.***

William C. Smith, ITA, Greer, SC 9/21/99

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